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Macaregua: the cave with the highest bat richness in Colombia

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Abstract: Bats provide crucial ecosystem services like pest control and pollination and depend heavily on roost quality for their survival. Bats favor caves for the establishment of large populations thanks to favorable microclimatic conditions. Colombia has an important cave system in the Santander region that has not been fully explored, thus its importance for bat conservation remains largely unknown. Here we report the most updated list of the species present in the Macaregua Cave (Santander, Colombia) and comment on its use by different species. We found eight species that use the cave permanently or sporadically in addition to two previously known species. We also found a high population that ranges between 7,000–10,000 individuals. Macaregua Cave can now be recognized as the most bat-diverse (S = 10) cave in Colombia, harboring an important bat population of pest controllers and seed dispersers.

Key words: Chiroptera, *Carollia, Mormoops, Natalus, Micronycteris*

INTRODUCTION

Bats are known to provide crucial ecosystem services, such as pest control and pollination (Kunz et al. 2011), but rely on the availability of suitable roosts for maintaining their populations (Kunz and Lumsden 2003). One of the main roosts used by bats are caves, which are dynamic and complex ecosystems. Within a cave, climatic conditions (i.e., temperature) can be stable for long periods of time and nutrient cycling and energy flow can take thousands of years (Culver and Pipan 2009). Nevertheless, water currents that traverse a cave system leach soil nutrients constantly, and fluctuating water currents that filters in from the exterior of the cave determines the chemical composition and structural shape of the cave's roof (Romero 2009). Caves are used by many species of bats as roosting sites, and some species depend heavily on caves throughout their life history (Murray and Kunz 2005). For example, many species use them as roosting sites for establishment and persistence, hibernation, or as a place to avoid predators and provide parental care (Glover and Altringham 2008; Berková and Zukal 2010). The constant microclimatic conditions in caves allow for the establishment of colonies of millions of individuals (Betke et al. 2008), which are known to save millions of dollars each year on pesticides to protect food crops (Kunz et al. 2011).

Aside from the ecosystem services bats provide outside of the caves, bats play an important role in the nutrient cycling of the caves themselves (Niu et al. 2007); they are one of the only organisms that enter and exit caves permanently, and by doing so they transport to these caves organisms such as seeds, fungal spores, fern spores, and microarthropods. Moreover, the guano bats produce accumulates and provides organic matter for soil organisms (Lopes et al. 2000). Bats themselves can be food for other organisms that inhabit the caves such as giant centipedes (Scolopendra), and occasional visitors such as snakes and medium sized mammals (Romero 2009).

The most intensively studied cave systems in Colombia are located in the departments of Antioquia, Boyacá, Huila, Tolima, and Santander (Muñoz-Saba et al. 1998). In the latter, 15 bat species from the families Phyllostomidae, Vespertilionidae, Mormoopidae, and Natalidae have been reported to inhabit cave systems (Muñoz-Saba et al. 2007). The most diverse family in the caves of Santander is Phyllostomidae, with 11 species (Muñoz-Saba et al. 2007). Aside from these sporadic studies, little is known about caves in Colombia, and despite their importance as a threatened ecosystem worldwide, caves in Colombia are facing strong anthropic pressure due to growing and uncontrolled tourism and unchecked speleological practices.

This research focuses on Macaregua Cave in Santander, Colombia. The last anecdotal information about this cave dates from the 1970s, with the work by Cadena

and Villarraga on *Natalus tumidirostris* Miller, 1900 and the first report for Colombia of the fungus *Histoplasma* carried out by Grose and Marinkelle (1970). Aiming to contribute to the research efforts in this cave system in Colombia, we describe here the composition of the bat assemblage in Macaregua Cave.

MATERIAL AND METHODS

Study area

Macaregua Cave (06°39′36.2″ N, 073°06′32.3″ W) is located in the county of San Francisco, municipality of Curití, department of Santander, Colombia (Figure 1). The altitude of its entrance is 1,565 m and it is situated in the Cordillera Boyacense-Santandereana biospeleological zone (Muñoz-Saba et al. 2007). The mean annual precipitation is 1,550 mm, with a unimodal rainfall pattern; a dry season from November to March, with precipitation that oscillates between 22 to 93 mm, and a rainy season from April until October, which ranges from 199 to 220 mm. The vegetation around the entrance of the cave is a tropical dry forest dominated by species from the families Boraginaceae, Fabaceae, Myrsinaceae, Rubiaceae and Caesalpiniaceae. Agriculture is the most important economic activity in the area; tobacco, coffee, beans, and maize are the most common crops. Agave is also planted for the production of "fique" (genus *Furcraea*), and cattle farming is also used as a mean of subsistence.

The cave has two main galleries; one is dry and approximately 80 m long, and the other has a running stream (henceforth moist gallery) and is approximately 610 m long (Figure 1). Another set of galleries (henceforth second set), which are approximately 180 m long, branch off from the moist gallery at 420 m. The moist galleries show a mean temperature of 25°C and 90% of relative humidity. The average height of the cave is 3.2 m, with some sections reaching 6 m. The cave's width ranges from 3 to 11 m, with two narrow (< 40 cm) and short (< 50 cm) ramifications of 55 and 65 m of length each (Figure 1). Pawlak and Szafranski (1977) determined that Macaregua was 770 m, but they did not specify if this measurement pertained to the moist gallery or to the combination of the dry and moist galleries. Given that they did not provide any other descriptor of the cave, it's not possible to assess any changes in its dimensions over time.

Methodology

We have visited the cave eight times (March and July/August 2010; January/February and November 2011; April, June, and November 2012; and February/March 2013) to study the social structure and activity patterns of the bats that inhabit the cave, especially those of *Carollia perspicillata* (Linnaeus, 1758). During these visits, we measured physical aspects of the different galleries and captured and identified bats throughout. Captures were done *ad libitum* using small mist nets and insect nets, and some bats were manually captured at their roosts. We also used a modification of the harp trap proposed by McCracken and Bradbury (1981), with a customized pocket made out of fabric with a lateral zipper and a string to close its uppermost part. In order to make a preliminary assessment of the number of individuals in the cave, we took photographs of the cave's roof and then counted the bats directly from the pictures. We corrected this estimate by directly counting bats while the roof was being photographed. Although we acknowledge this technique might produce over or underestimations, our direct counts did not differ from the number of bats we were able to count from the photographs.

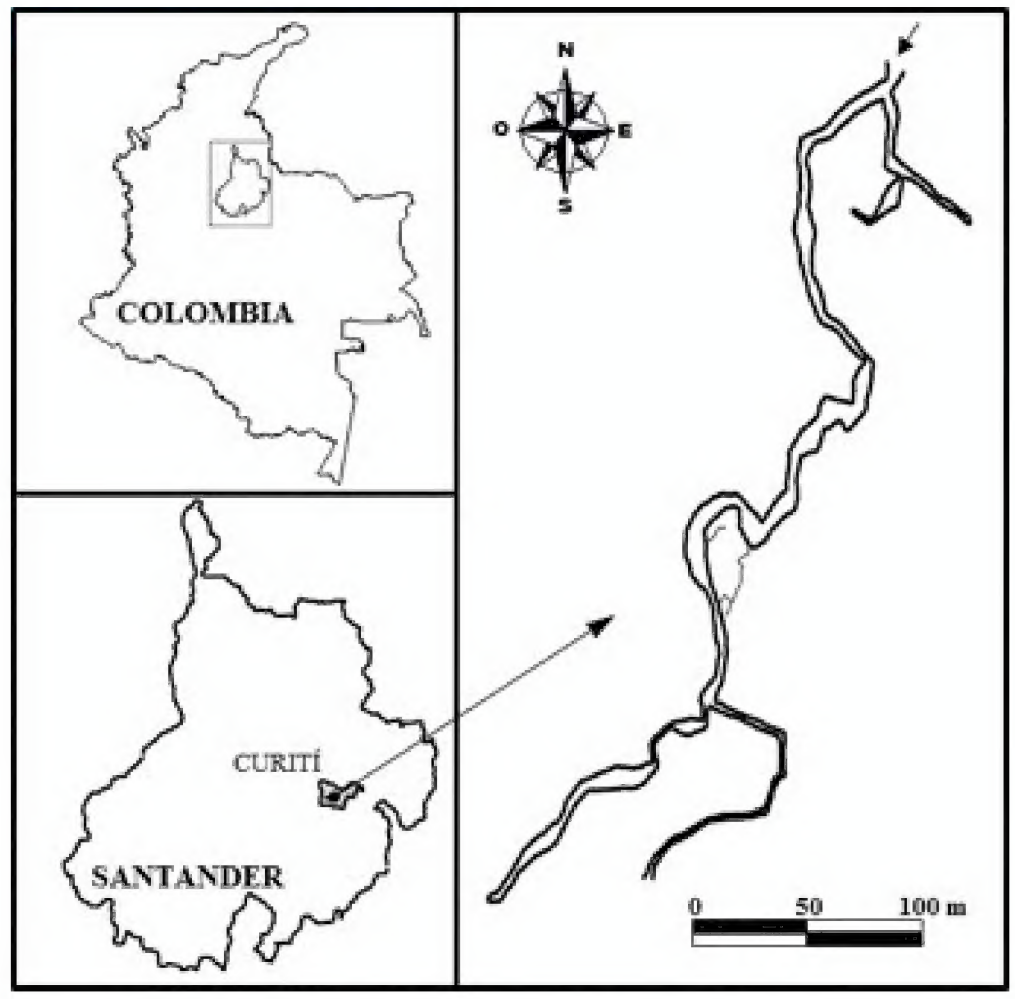

Figure 1. Location of the Macaregua cave in Santander, Colombia. Arrow at the right hand corner of the rightmost panel indicates the entrance of the cave.

Each captured individual was measured using standard procedures (Tirira 2007). We measured their total length and weight, length of tail, foot, ear, forearm, wingspan, tragus, leaf nose, calcar, and pollex. Reproductive status was recorded following Racey (2009). Bats were identified using the keys by Timm and LaVal (1998) and Linares (1998) and were released afterwards. Some individuals were collected as vouchers and deposited in the Museo Javeriano de Historia Natural (MUJ) (collection numbers MUJ 1720–1808, permit DLG No. 00001153 issued by Corporación Autónoma Regional de Santander C.A.S.). We followed the guidelines proposed by Sikes and Gannon (2011) to euthanize specimens, thus complying with the voucher policy of Check List. We used the nomenclature suggested by Simmons (2005) and adopted the current classification for the bats of Colombia (Solari et al. 2013). For analysis, bats were

grouped into trophic guilds according to Schnitzler and Kalko (2001). Aside from direct captures, we performed a literature and a data base survey of available collections in Colombia and elsewhere to complete the catalogue of the species that have been registered in the cave. To do so, we consulted the curators of the collections deposited in the Universidad de Antioquia (Medellín), La Salle Museum (Bogotá), and Universidad del Valle (Cali), and searched the online catalog of the mammal collection in the Instituto de Ciencias Naturales (ICN) (http://www.biovirtual.unal.edu.co/ICN/). We performed a final query in the VertNet database using the word "Macaregua" as search key (http://portal.vertnet.org/). We acknowledge that there are other specimens captured in Macaregua deposited in other collections. Nevertheless, we based our account on data we have collected and used references from other collections only when we did not have vouchers from those species (e.g., *Micronycteris megalotis* (Gray, 1842); see Table 1).

RESULTS

With our captures and direct observations we found eight species inhabiting the Macaregua Cave, comprising four families: Phyllostomidae, Vespertilionidae, Natalidae, and Mormoopidae (Table 1). *Carollia perspicillata* was the most abundant species, followed by *Mormoops megalophylla* (Peters, 1864) and *Natalus tumidirostris*. According to our photograph counts, we estimate that the total number of bats in the cave ranges between 7,000 and 10,000 individuals. Species were not randomly distributed across the cave. For example, *Desmodus rotundus* (É. Geoffroy, 1810) generally used deep crevices in the roof, where it formed compact groups, and was only found between 170 m and 290 m from the entrance. In comparison, *C. perspicillata* formed harems in shallow crevices and rocks protruding from the roof after the first few meters from the entrance but only up to 500 m. *Mormoops megalophylla* was found mainly in the deepest section of the second set of moist galleries of the cave, at 550–600 m from the entrance, and with few individuals along the curse of the water stream. Occasionally, we found some individuals in the dry gallery between 20 and 80 m. *Myotis nigricans* (Schinz, 1821) was also found occasionally in the dry gallery at 20 m. *Natalus tumidirostris* and *M. megalophylla* shared the second set of moist galleries, but the former mainly uses the last 200 m of the cave. Its population fluctuates around 500 individuals. After giving birth, *N. tumidirostris* creates cohesive maternity nurseries in this area of the cave. *Micronycteris schmidtorum* Sanborn, 1935 was found twice (April and November 2012) at 70 m from the entrance in the moist gallery. One individual of *Dermanura bogotensis* (K. Andersen, 1906) was captured in the first meters of the cave and one individual of *Glossophaga soricina* (Pallas, 1766) between 100 and 150 m from the entrance.

The set of species found at Macaregua comprises five trophic guilds: background-cluttered space aerial insectivores, highly cluttered space gleaning insectivores, frugivorous, nectarivorous, and hematophagous. About half of the counted individuals were the frugivorous *C. perspicillata*, but insectivorous bats, represented by two guilds, show the highest richness

Table 1. Bat species recorded for the Macaregua Cave, Santander, Colombia, and related ecological data. Guilds: background-cluttered space aerial insectivores (BCAI), highly cluttered space gleaning insectivores (HCGI), frugivorous (F), hematophagous (H), and nectarivorous (N). Functional groups: pest controller (PC), seed disperser (SD), potential disease transmitter (PDT), and pollinator (P). Abundance: super abundant (SA) (> 5,000), abundant (A) (> 500–5,000), infrequent (I) (> 50–500), and rare (R) (1–50). See text for abundance estimation criteria and institutional acronyms.

Family	Subfamily	Species	Guild	Functional group	Source	Abundance
Mormoopidae		*Mormoops megalophylla* (Peters, 1864)	BCAI	PC	* MUJ 1720–1722, 1724–1725, 1736–1737, 1809, 1812, 1817	A
Vespertilionidae	Myotinae	*Myotis nigricans* (Schinz, 1821)	BCAI	PC	* MUJ 1815	R
Natalidae		*Natalus tumidirostris* Miller, 1900	BCAI	PC	* MUJ 1723, 1726, 1728, 1738–1739, 1810–1811	A
Phyllostomidae	Carolliinae	*Carollia perspicillata* (Linnaeus, 1758)	F	SD	* MUJ 1727, 1729, 1731–1734, 1741, 1743–1803, 1813, 1816, 1818	SA
	Desmodontinae	*Desmodus rotundus* (É. Geoffroy, 1810)	H	PDT	*	I
	Phyllostominae	*Micronycteris schmidtorum* Sanborn, 1935	HCGI	PC	* MUJ 1735, 1814	R
		Micronycteris megalotis (Gray, 1842)	HCGI	PC	ICN	R
	Glossophaginae	*Glossophaga soricina* (Pallas, 1766)	N	P	* MUJ 1742	R
		Anoura caudifer (É. Geoffroy, 1818)	N	P	ICN 19495	R
	Stenodermatinae	*Dermanura bogotensis* (K. Andersen, 1906)	F	SD	* MUJ 2187	R

* This report.

(S = 5). According to our data, the literature review, and the database query, Macaregua Cave harbors at least ten bat species (Table 1).

DISCUSSION

The available information indicates that Macaregua Cave holds the richest bat community of any cave in Colombia (Muñoz-Saba et al. 1998; Muñoz-Saba et al. 2007; Sampedro-Marín et al. 2007; Sampedro-Marín and Mendoza 2009). The next most speciose cave is the Caja de Agua Cave (department of Huila) with six species (Muñoz-Saba et al. 2007). At a continental scale, the Olhos d' Água Cave and Las Vegas Cave, in Brazil and México respectively, are the most speciose caves in America, with 13 species (Medellín and López-Forment 1985; Trajano and Gimenez 1998), followed by the Actun Lol-Tun Cave, Mexico, with 12 species (Arita 1996). According to criteria proposed by Arita (1993), the abundance of individuals found in Macaregua Cave is high (> 1,000 individuals). At a regional scale, the ten species we report constitute 30% of the species found in the department of Santander (Solari et al. 2013) and 44% of the species registered for the cave system in this department (Muñoz-Saba et al. 2013). The query in the online catalogue of the mammal collection of the Instituto de Ciencias Naturales of the Universidad Nacional de Colombia showed that 24 species have been registered for the cave system in the department of Santander. Hence, Macaregua Cave has 41.6% of the total species richness found in the area. This highlights that Macaregua harbors a representative assemblage of species at the regional scale and constitutes a key element for the conservation of Colombian bats.

Mormoops megalophylla was first collected in Macaregua by P. Hershkovitz in 1951 (Field Museum of Natural History: FMNH 72130–72140, 72297–72335), and then later, in 1966, by C. Marinkelle, who collected a series of 19 specimens (ICN 5576–5594). According to Muñoz-Saba et al. (2013), *M. megalophylla* has also been reported in the El Yeso, La Antigua, and El Nitro caves. Our report also confirms the presence of *M. nigricans* using caves in Colombia, and it is a new record for the bats that inhabit Macaregua. As a comparison, *Myotis keaysi* J.A. Allen, 1914 has been reported for the El Tigre and La Virgen caves (ICN 17507-17509; 17635-17639) and *Myotis oxyotus* (Peters, 1867) for El Nitro and La Alsacia caves (MUJ 1586-1587), both in the department of Santander.

The formation of maternity nurseries reported here for *N. tumidirostris* has been observed occasionally in the Santander cave system since the mid-seventies (Cadena and Villarraga, pers. com. that dates 1974; Martínez-Luque pers. obs. 2004; Estrada-Villegas pers. obs. 2007; Pérez-Torres pers. obs. 2010). This species was first collected in Macaregua by A. Rouhaire (Hno. Nicéforo María) in 1948 (Museo La Salle: 1118), with additional specimens collected by P. Hershkovitz in 1951 (FMNH 72125–72129, 72190–72196), C. Marinkelle in 1967 (ICN 5542–5550), and L.E. Villarraga from 1967–1969 (Universidad de los Andes; Andes-M 429, 676, 716–718, 802–819, 1586, 1881, 1891, 1905, 1911, 1913–1915). There is also a large series of 164 specimens collected by M. Gómez-Laverde between 1983 and 1984 (ICN 8537–8540, 8548–9084). According to Muñoz-Saba et al. (2013), *N. tumidirostris* is also reported for the El Indio de Doña Joaquina, El Rascadero, and El Nitro caves.

Carollia perspicillata is a frugivorous bat that disperses large amounts of seeds of pioneer species and is fundamental in forest regeneration (Altringham 2011). In addition to Macaregua, this species has also been reported for Resumidero and La Antigua caves (ICN 19559-19560; 17644–17647), El Nitro and La Alsacia caves (MUJ 1582, 1584), and 17 other caves in Santander (Muñoz-Saba et al. 2013). *Desmodus rotundus* was first collected in Macaregua in 1948 (MLS 1119) by A. Rouhaire (Hno. Nicéforo María). This species has been recorded from 19 other caves in Santander, including the Muerto, La Iglesia, and La Antigua caves (ICN 19508; 17504–17506; 17649–17651). *Glossophaga soricina* and *M. schmidtorum* probably use the cave sporadically. Only three individuals have been captured during the years we have visited the cave, and they were roosting alone. *Glossophaga soricina* has been reported in other caves in Santander (El Saun, La Antigua, El Muerto, and El Nitro), Huila (Caja de Agua), and Tolima (La Carbonera and El Tigre) (Muñoz-Saba et al. 2007, 2013), but this is the first record for *M. schmidtorum*. Our data also represent the first report of *D. bogotensis* using caves in Colombia. However, because we captured only one individual (MUJ 2187), and it was located in the first few meters of the cave, its presence could be accidental and needs further investigation.

Aside from our direct observations, Muñoz-Saba et al. (2013) reported *Anoura caudifer* (É Geoffroy, 1818) (ICN 19495) and *M. megalotis* (ICN 19499) for Macaregua, and we included these two species in our report. *Micronycteris megalotis* has also been found in other caves in Santander; El Chulo and El Escaño caves (Muñoz-Saba et al. 2013). Muñoz-Saba et al. (2013) also reported *Carollia brevicauda* (Schinz, 1821) and *Leptonycteris curasoae* Miller, 1900 for Macaregua Cave. However, the former is a misidentification—we reviewed the vouchers cited by Muñoz-Saba et al. (2013) and concluded they are in fact specimens of *C. perspicillata*—and, for the latter, Muñoz-Saba et al. (2013) did not provide supporting vouchers. Marinkelle and Grose (1968) reported the presence of *Leptonycteris nivalis* (Saussure, 1860) in Macaregua, but their record may represent *L. curasoae* according to the current distribution of these species. These authors also did not provide a voucher specimen.

Finally, our study adds three new species for the list provided by Muñoz-Saba et al. (2013) for the bats of the cave system of Santander: *M. nigricans*, *M. schmidtorum*, and *D. bogotensis*.

The caves in the department of Santander contribute to the persistence of bat species at a regional scale because they are intensively used for resting and reproduction. With this study, we confirm that this is the case for the bats that inhabit Macaregua Cave. There is a need, however, for more research addressing detailed aspects of the ecology and functional importance of the bats present in Macaregua and other caves in the region. These studies will potentially highlight the importance of bats as providers of key ecosystem services (e.g., biological control of pests, seed dispersal and pollination) and reinforce the need to protect the cave systems in Santander and in other departments in Colombia.

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